CEPC Detector Optimization

FCPPL 2018 @ Marseille

23/05/2018

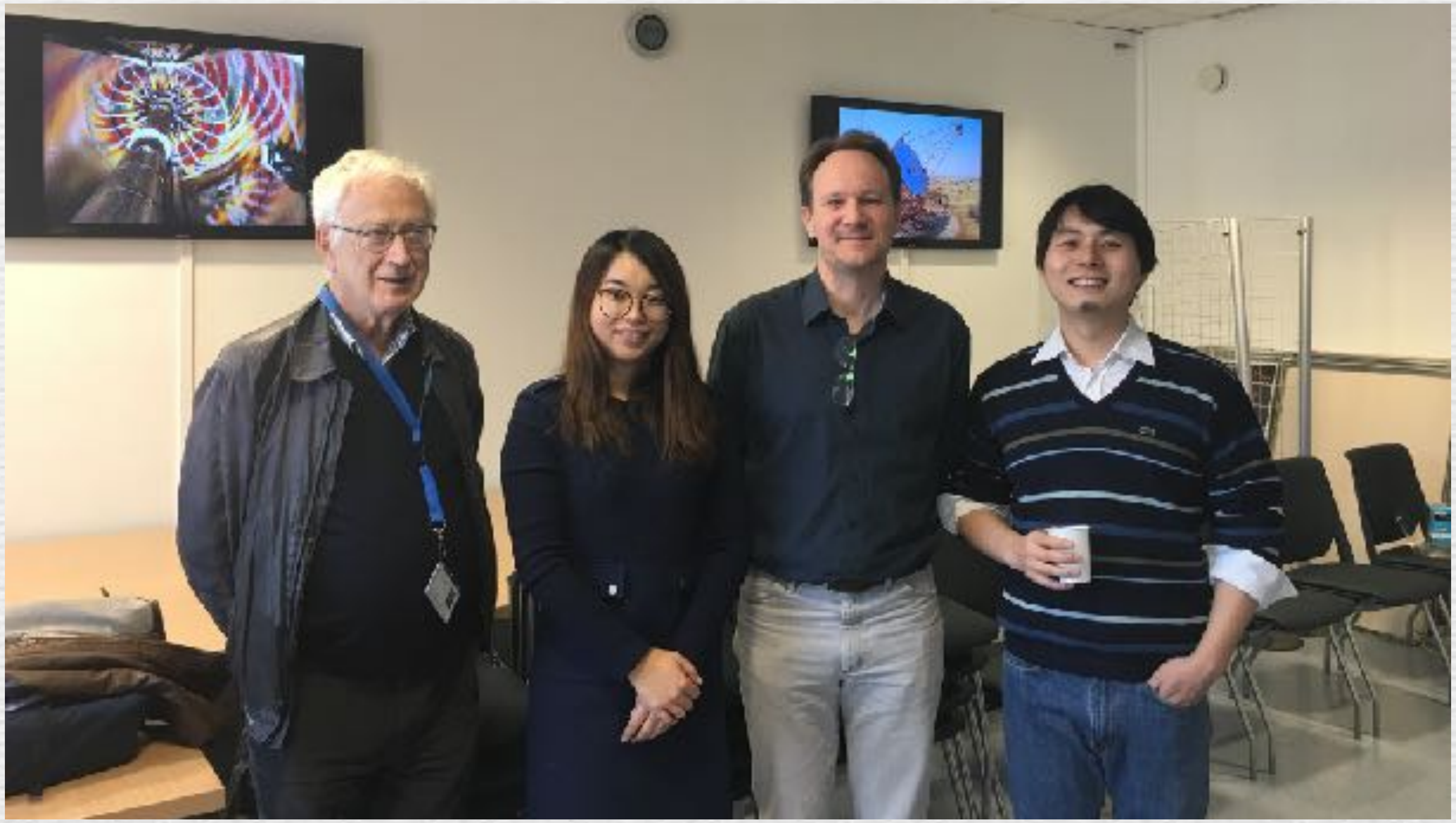
ÉCOLE POLYTECHNIQUE

UNIVERSITÉ PARIS-SACLAY

Projets

- Collaboration:
  - IHEP: RUAN Manqi, LI Gang, YU Dan, ZHAO Hang, …
  - LLR: Vincent BOUDRY, Jean-Claude BRIENT, Vladislav BALAGURA, Marc ANDUZE, Emilia BECHEVA
- ECAL
  - Prototype, optimization (cooling), algorithm…

→ Co-supervised Thesis Feb 2018

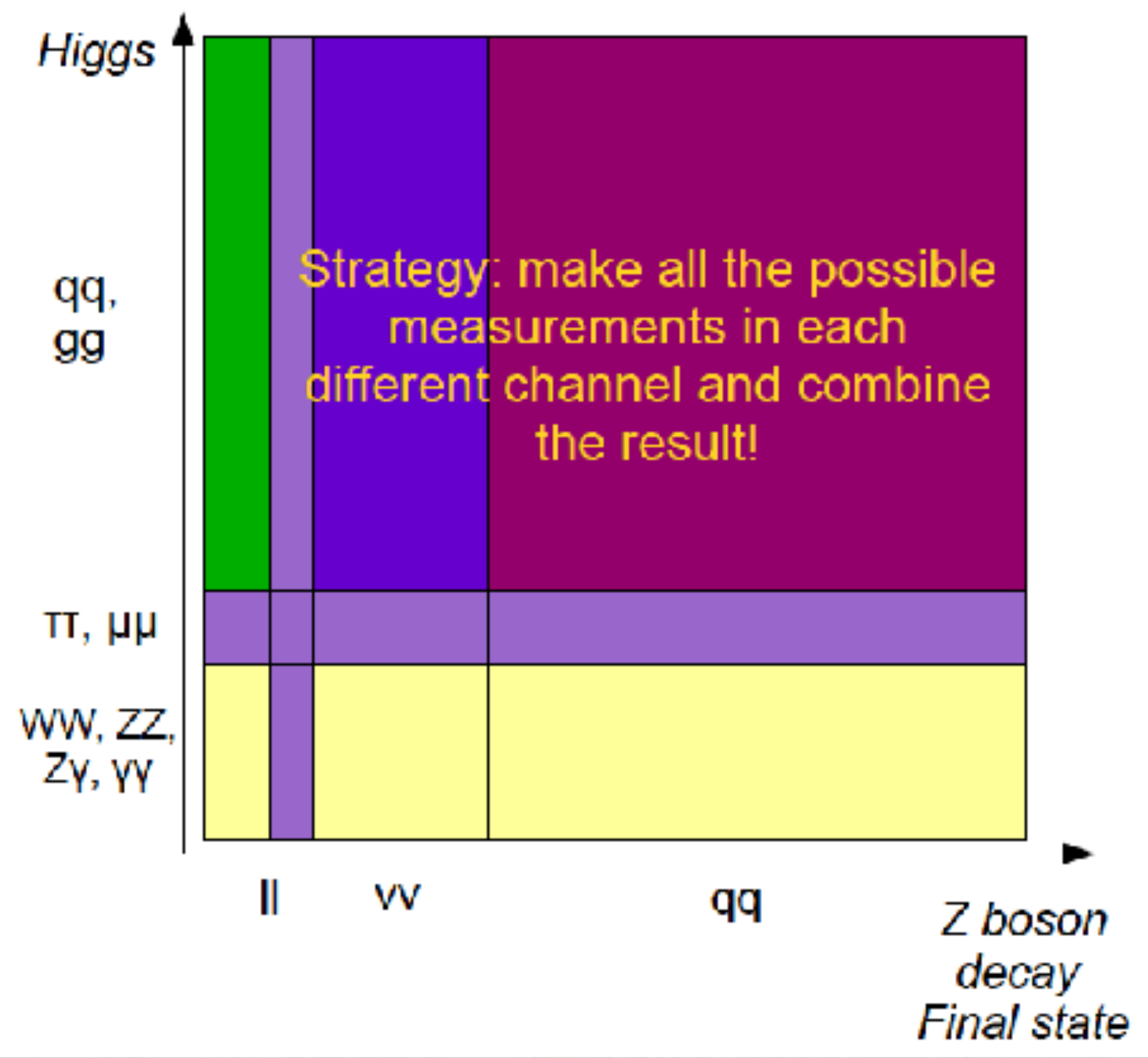


Outline

- PFA - ArborLICH - Tools
- Detector Optimization
  - ECAL
  - HCAL
  - B Field
- Baseline for CEPC CDR & Physics Performance

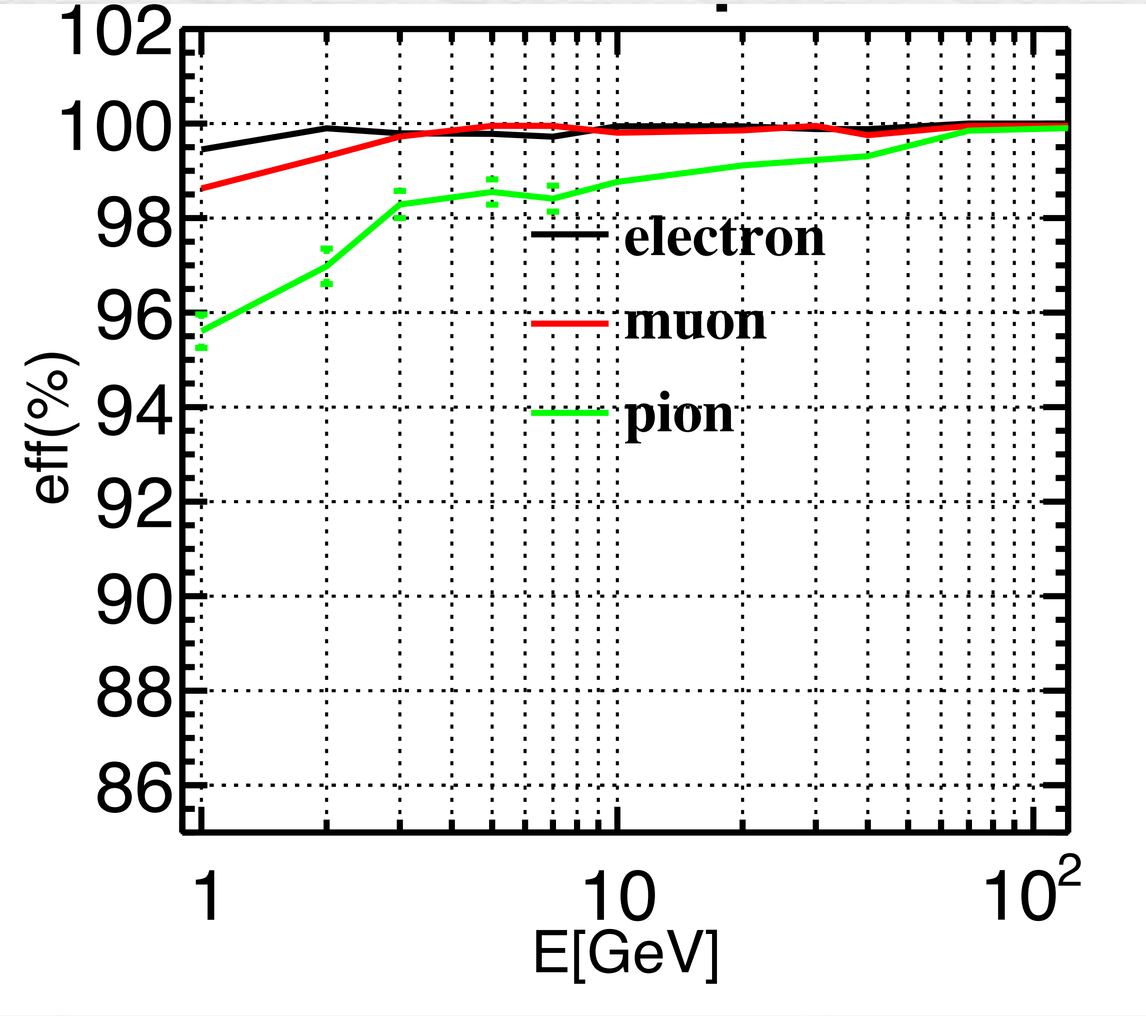
PFA & Benchmarks

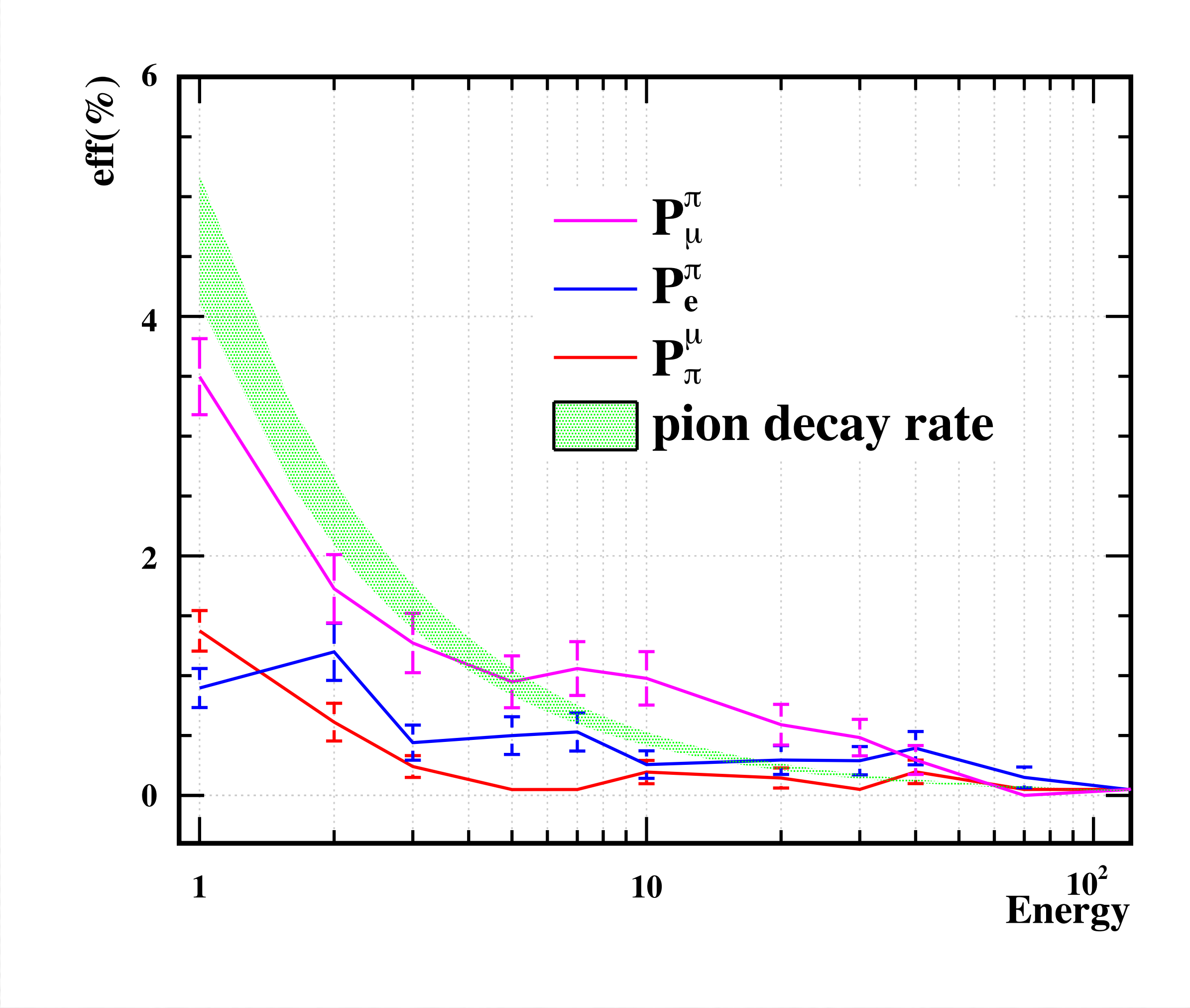
- Objective performance
  - Lepton
  - Kaon
  - Photon
  - Tau
  - Jet



LICH - lepton identification

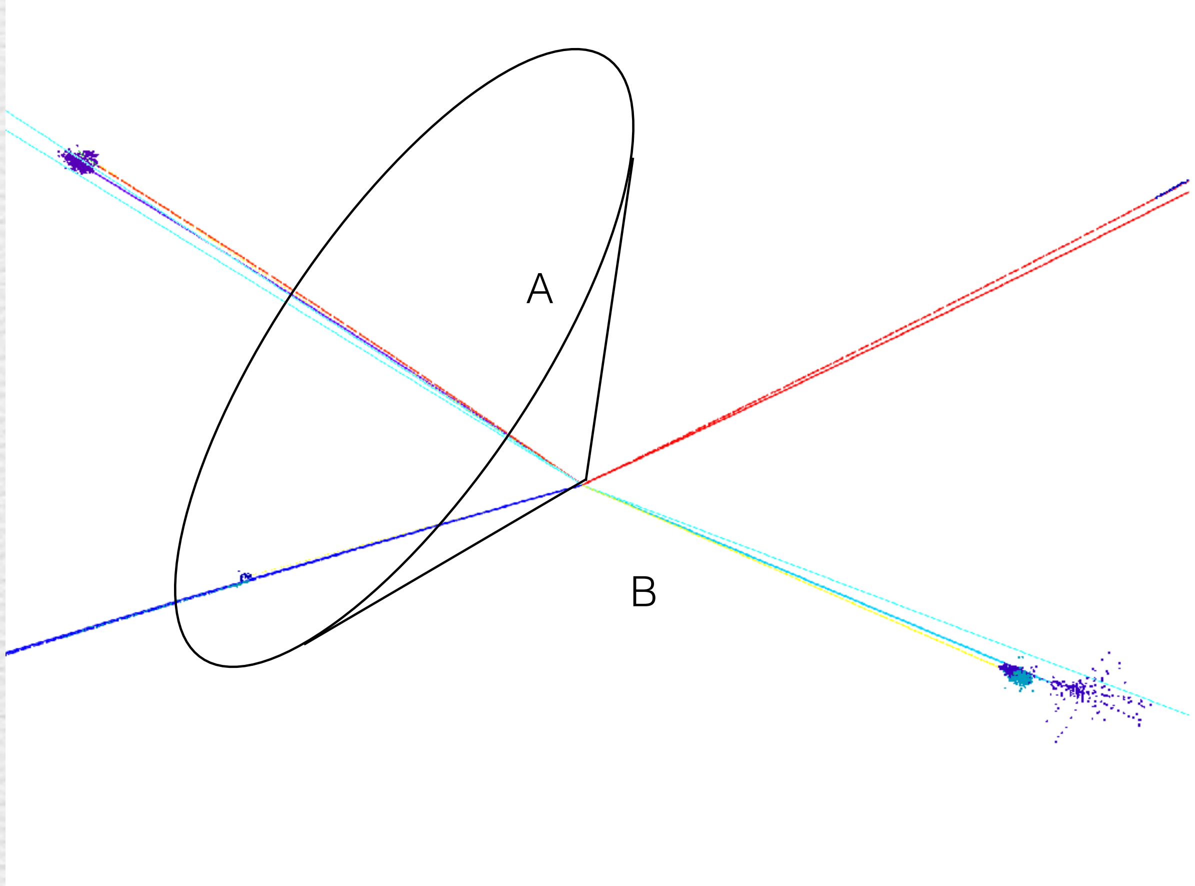
- TMVA based, PFA independent package: Lepton Identification for Calorimeter with High granularity
- Input: 24 variables from reconstructed charged particle
  - dE/dx, Fractal Dimension, …
- Efficiency comparable to ALEPH, mis-id rates significantly improved
- Physics event: consistant result with single particle level

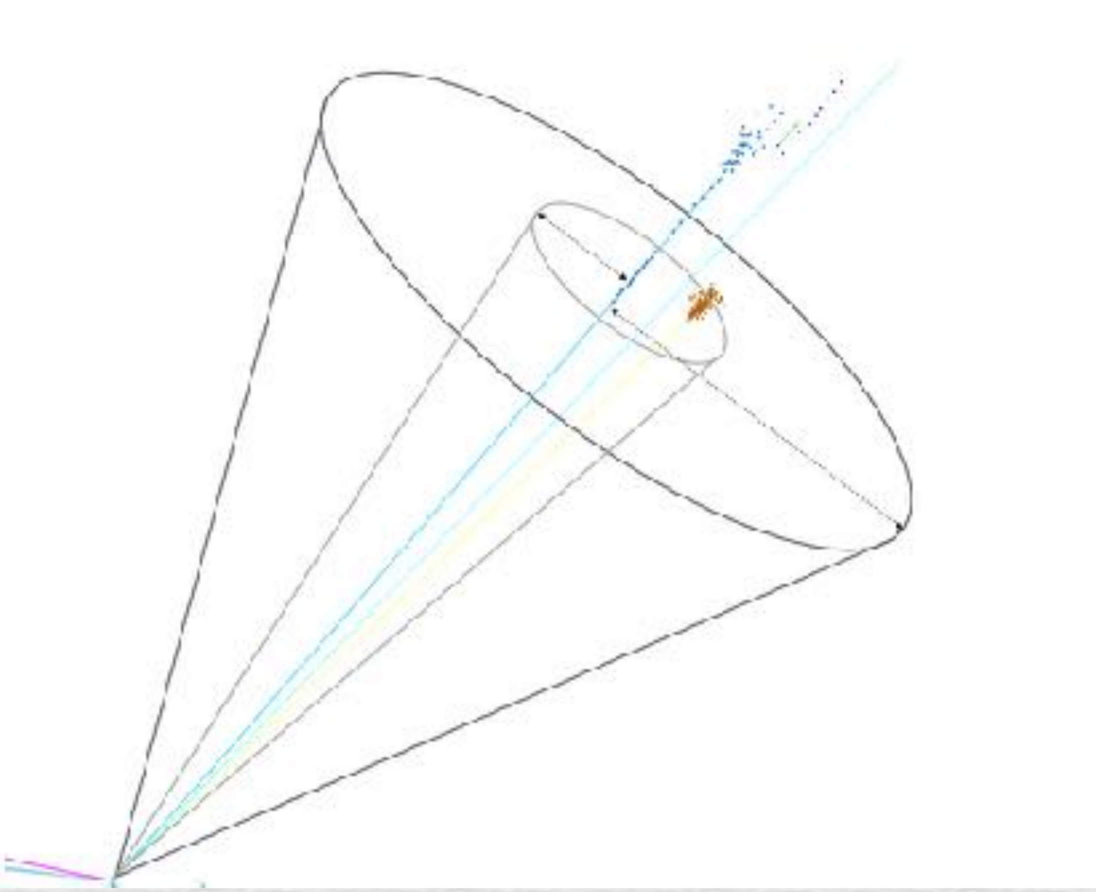




Higgs to Tau Signal Strength

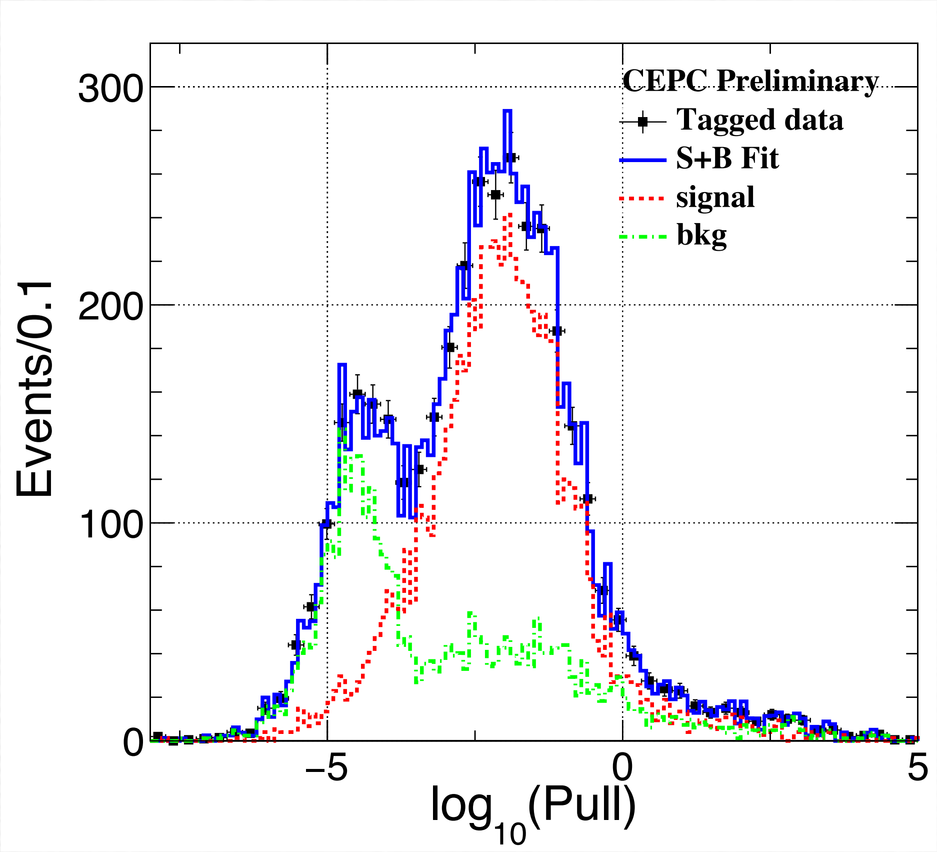
- High efficiency and purity identification of τ candidates
  - llH: number counting after lepton veto
  - qqH: Cone based finding algorithm and use precisely reconstructed final states

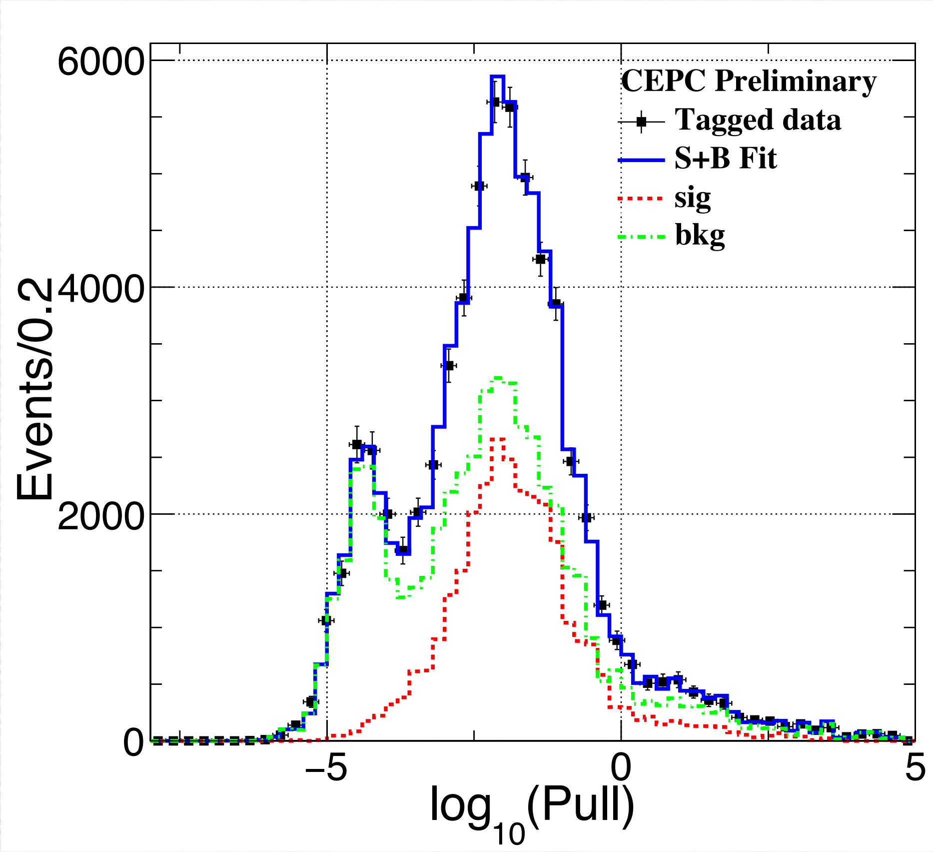




Higgs to Tau Signal Strength

- Take advantage of the vertex detector



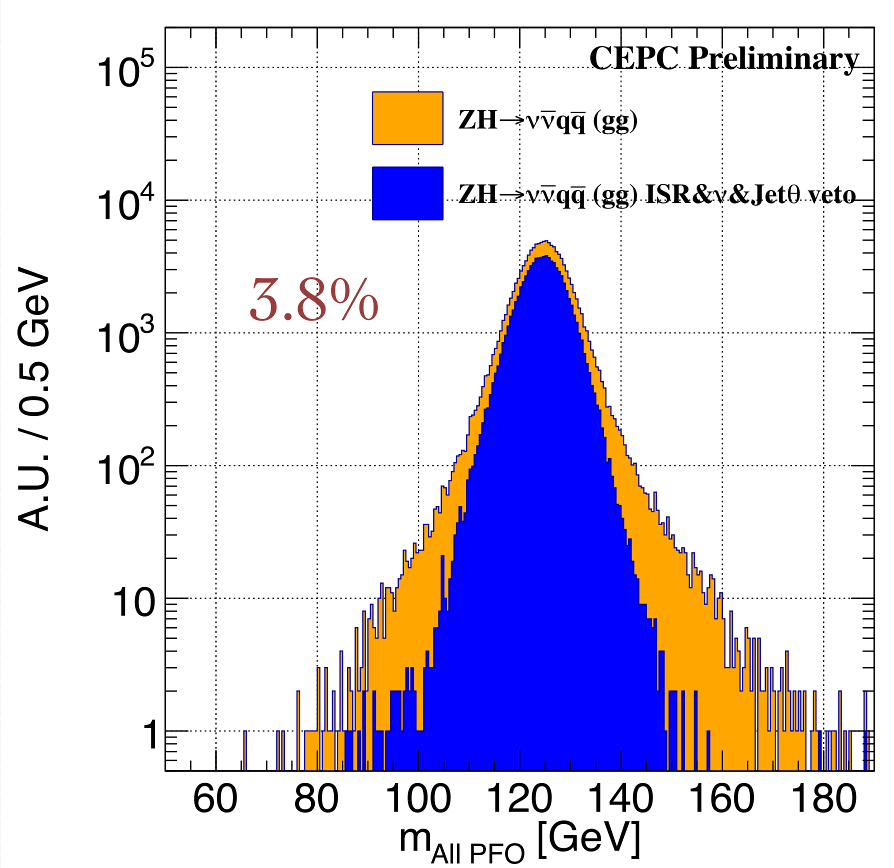


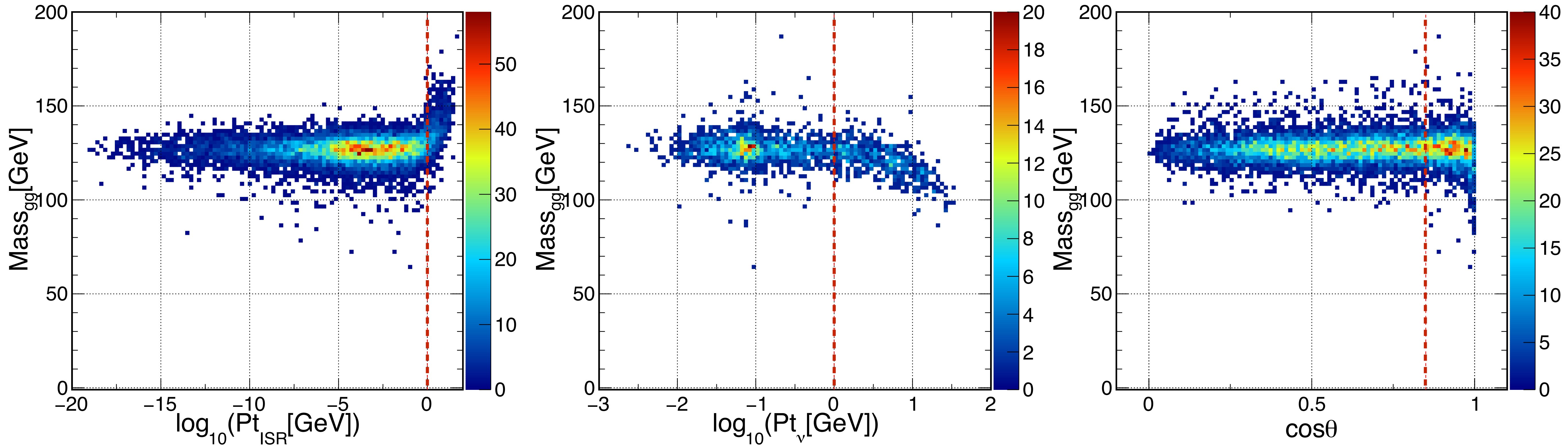
H→ττ signal strength (CEPC 5ab^{-1})

	mumuH	eeH	nnH	qqH	combination
δ(σ×Br)/(σ×Br)	2.26%	2.72%	4.29%	0.93%	0.81%

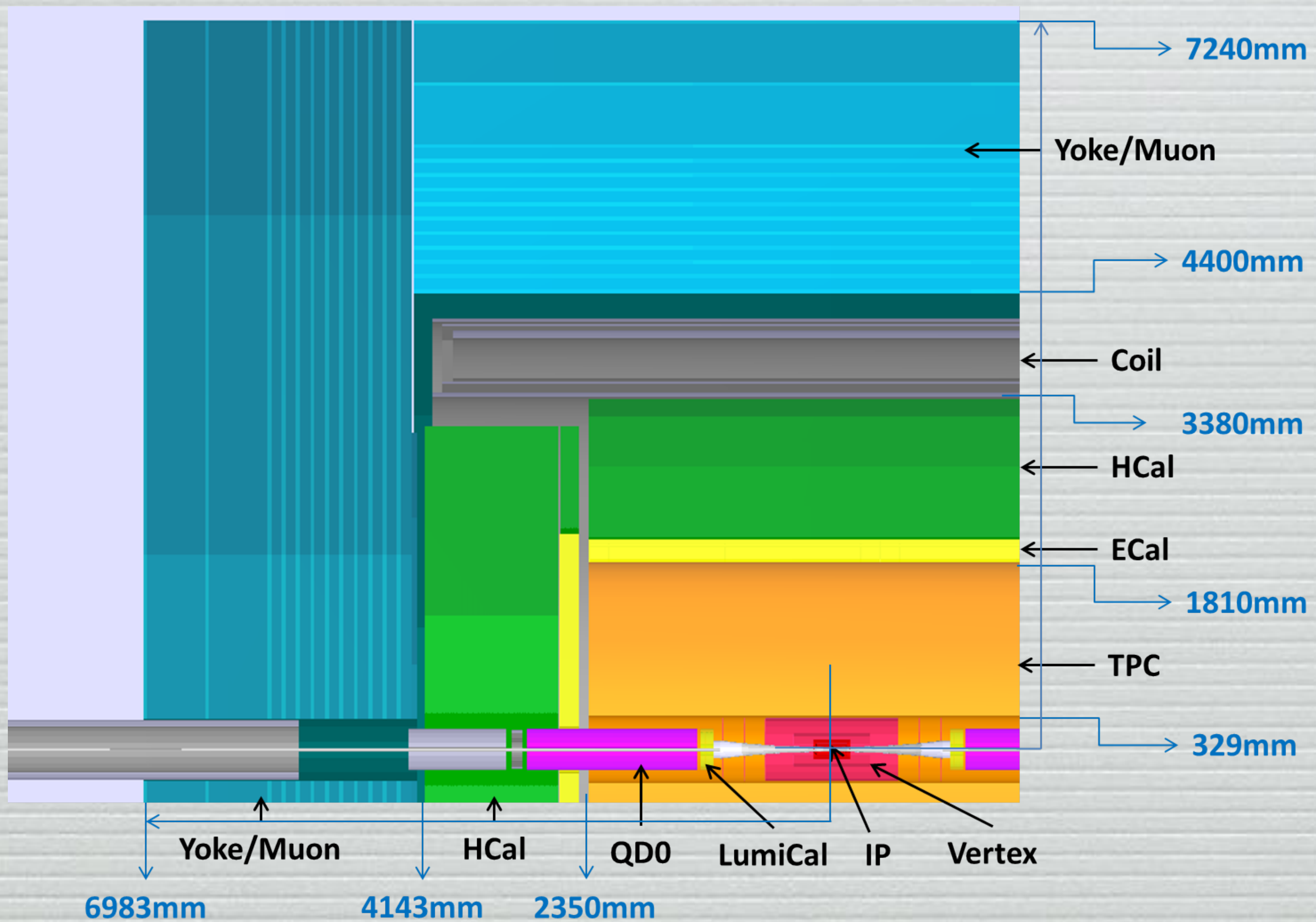
Arbor Performance

- Higgs Boson Mass Resolution in vvgg channel (BMR)
- Focus on influence from algorithm/detector
- Rejection: ISR photons, neutrinos from the Higgs, jets shooting to the endcaps
- Frame for algorithm/detector optimization





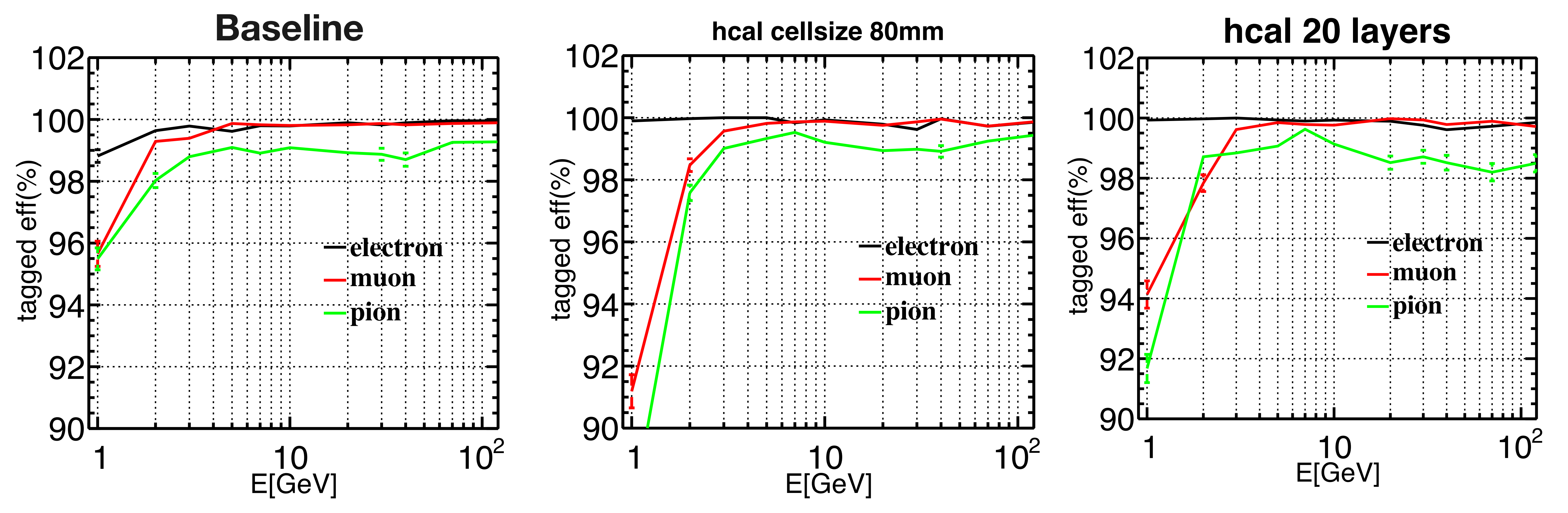
Optimization



CEPC V1 Detector
~ILD
(up to 1 TeV)

Lepton ID @ different geometries

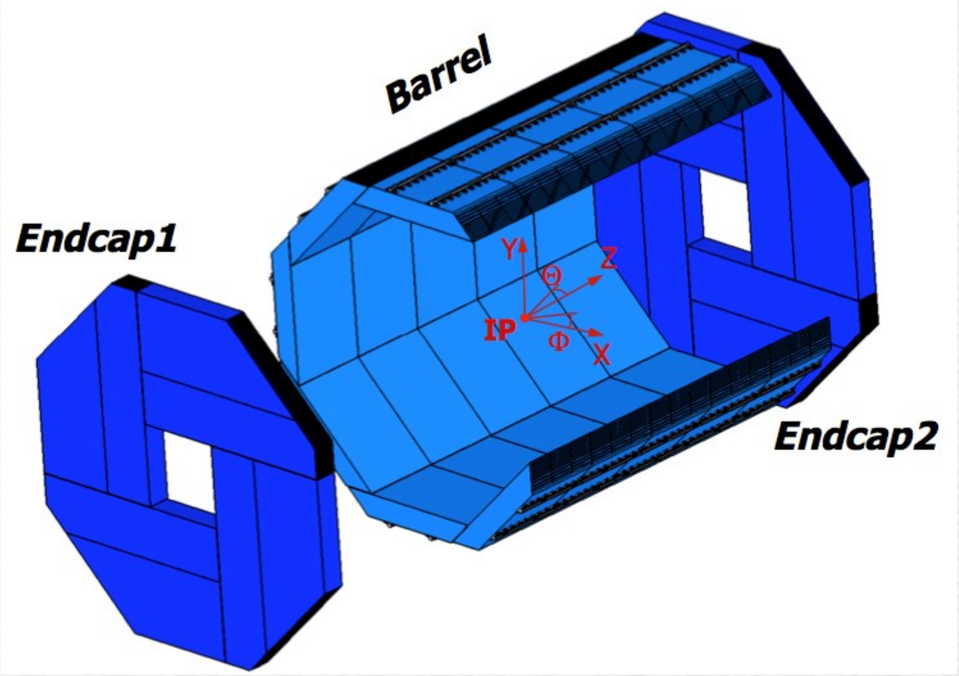
- Single lepton identification efficiency
  - ECAL: 20-30 layers, 5×5mm^2 - 40×40mm^2
  - HCAL: 48-20 layers, 10×10mm^2 - 80×80mm^2

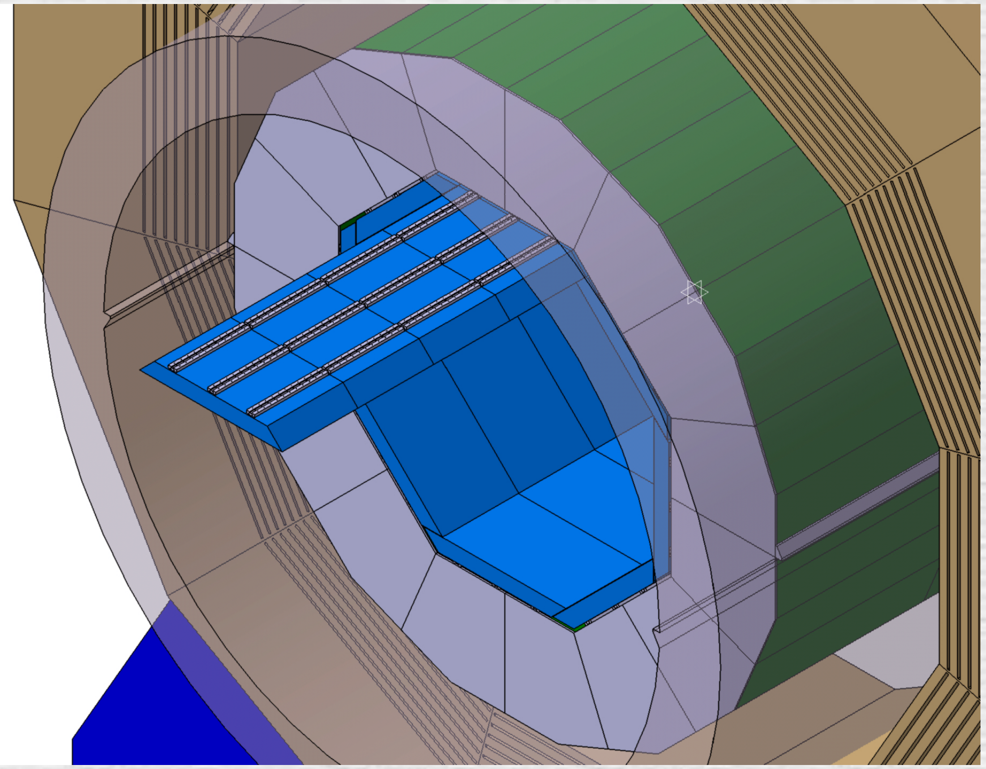


- Event efficiency: mumuH efficiency degrades from 98.53 ± 0.13% to 97.24 ± 0.18% while readout channels 7/8 reduced

ECAL Optimization

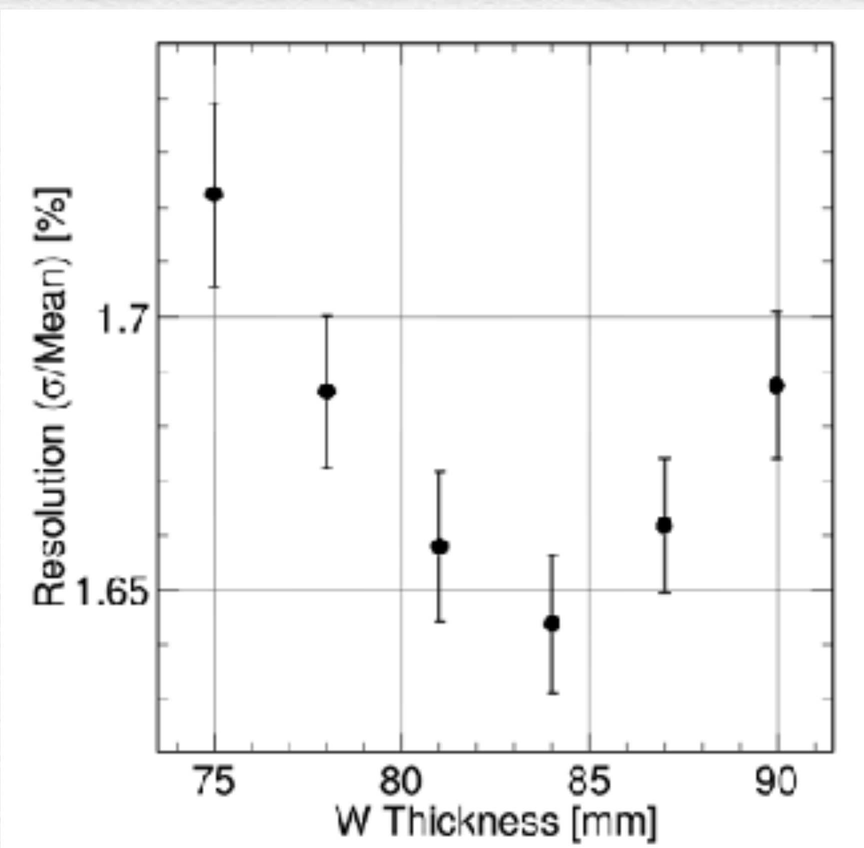
- Baseline: 30 layers
  - Absorber: 20×2.1cm+9×4.2cm
  - Sensor:
    - thickness: 0.5mm
    - Cell size: 5mm×5mm
- Optimization options:
  - Total Absorber Thickness
  - Number of Layers (while total absorber thickness remains the same)
  - Sensor thickness
  - Cell sizes
- Mokka & Arbor version3.3

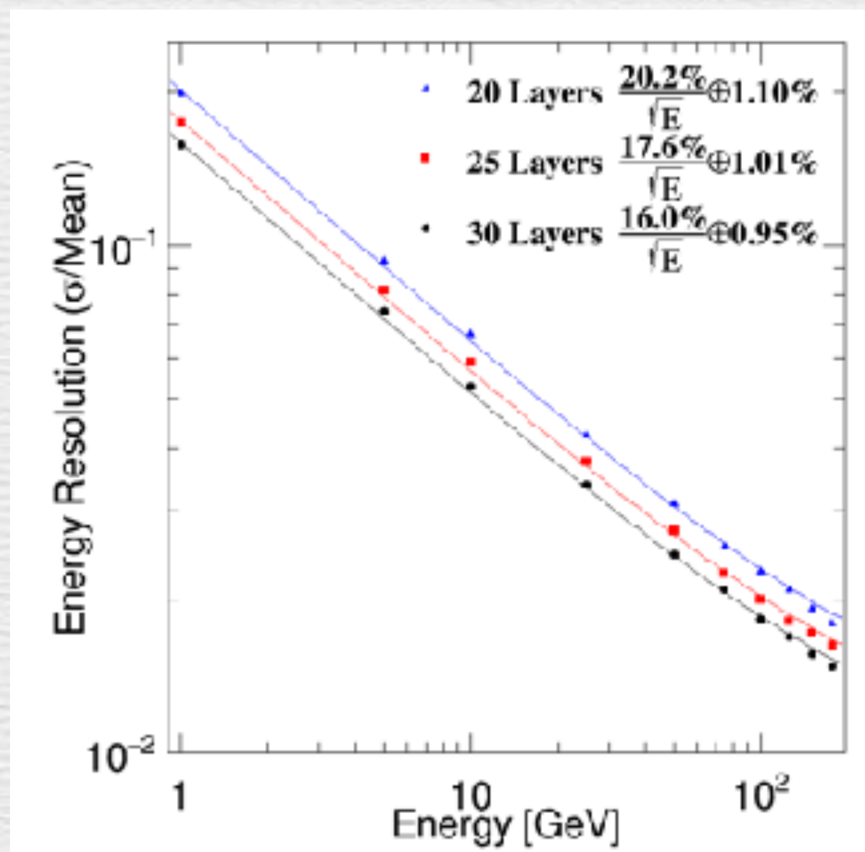


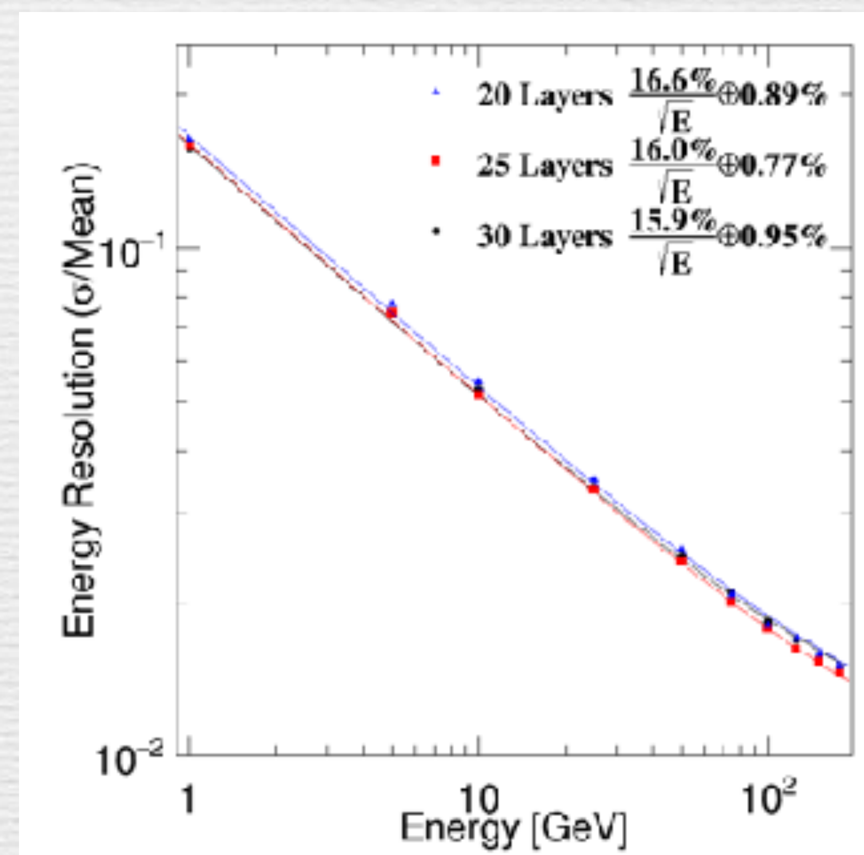


ECAL Longitudinal Structure

- Absorber thickness
  - Di-photon resolution in H→γγ
- Layers (total thickness remains the same)
  - 30, 25, 20
  - Di-photon resolution
- Layers & sensor thickness
  - (30L, 0.5 mm), (25L, 1mm), (20L, 1.5mm)
  - Thicker silicon sensor layers compensate the degrading





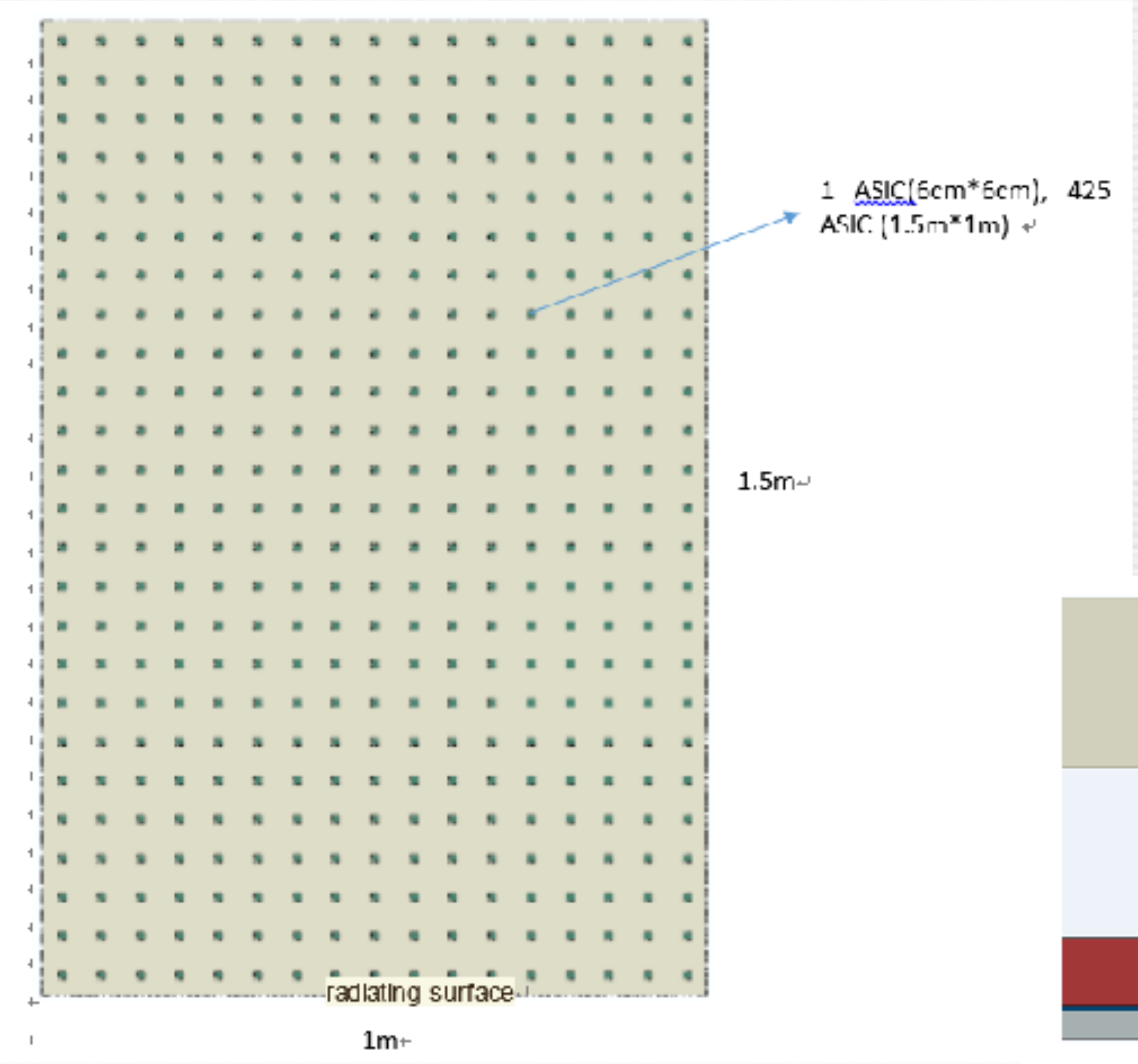


ECAL Cell Size

- To reduce the readout channels: no passive cooling
- Separation performances vs particle distances
- BMR

Cell Size (mm^2)	5×5	10×10	20×20
BMR	3.74 ± 0.02 %	3.75 ± 0.02 %	3.93 ± 0.02 %

Cooling system

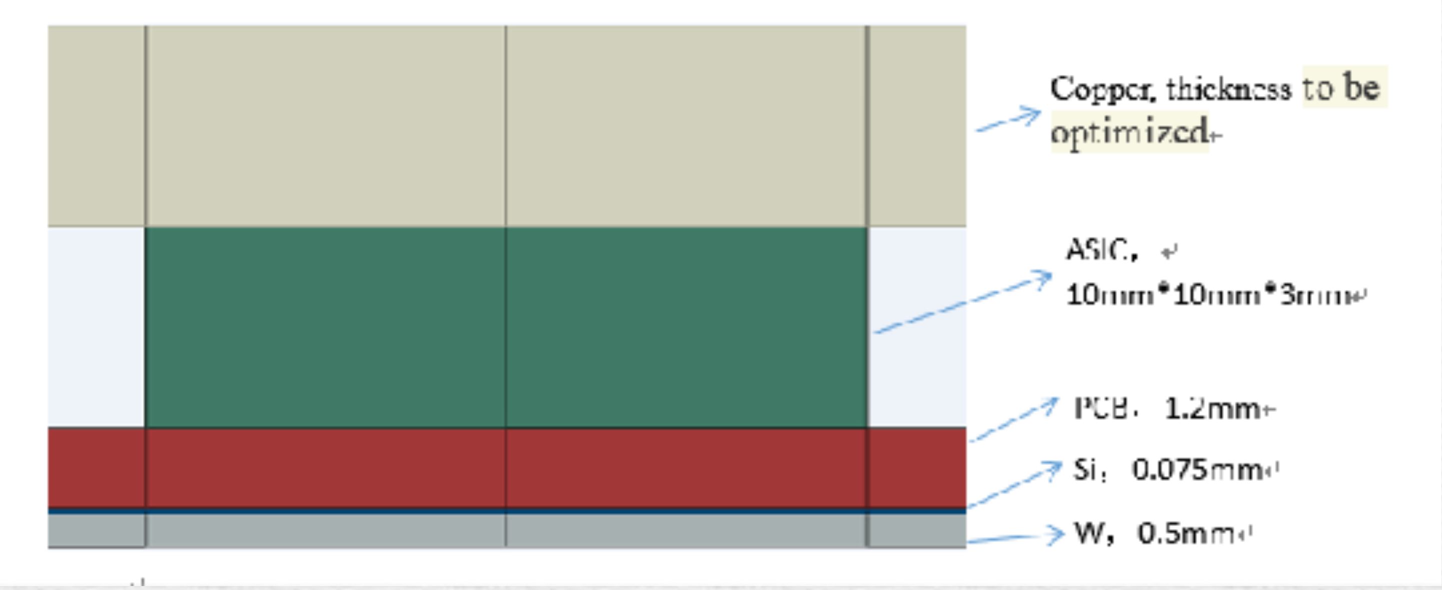


Thermal contact resistance :1000W/m^2*K

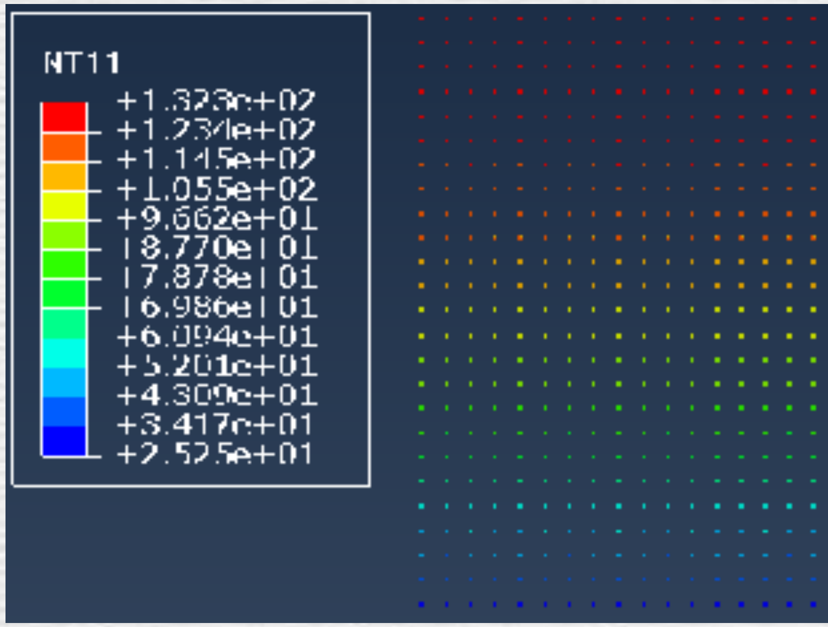
The temperature of radiating surface： 20°C

The heat rate of 1 ASIC: 0.36W

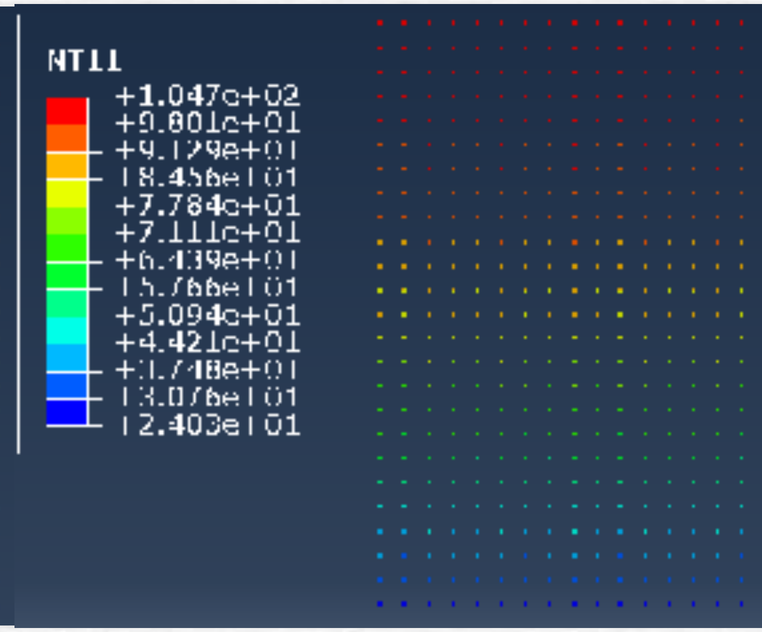
ABAQUS FEM Simulation



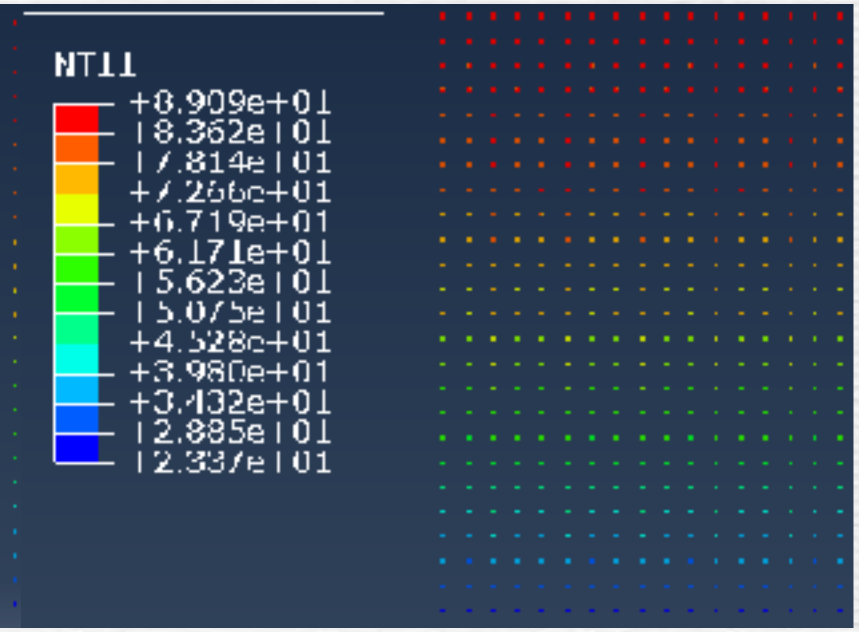
Cooling system



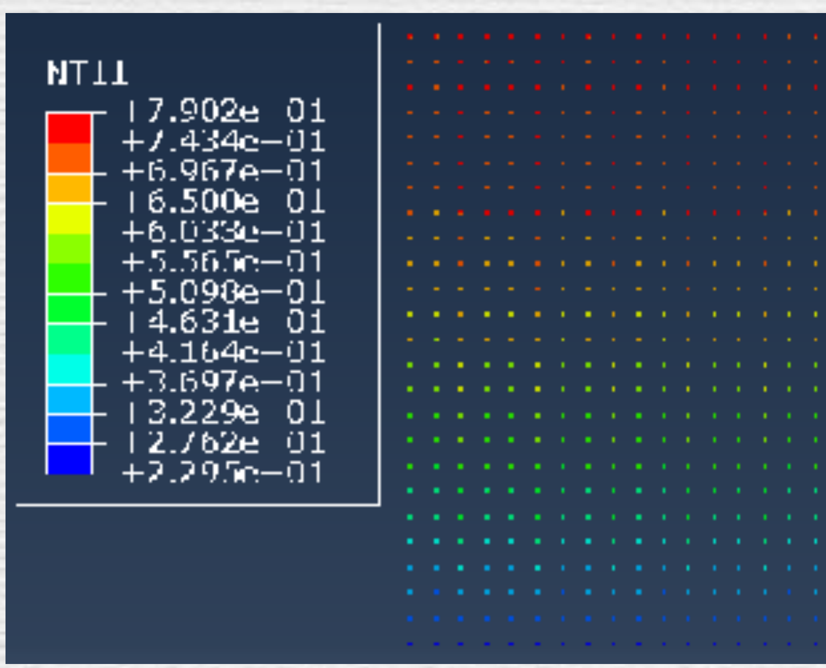
Temperature distribution（1mm）



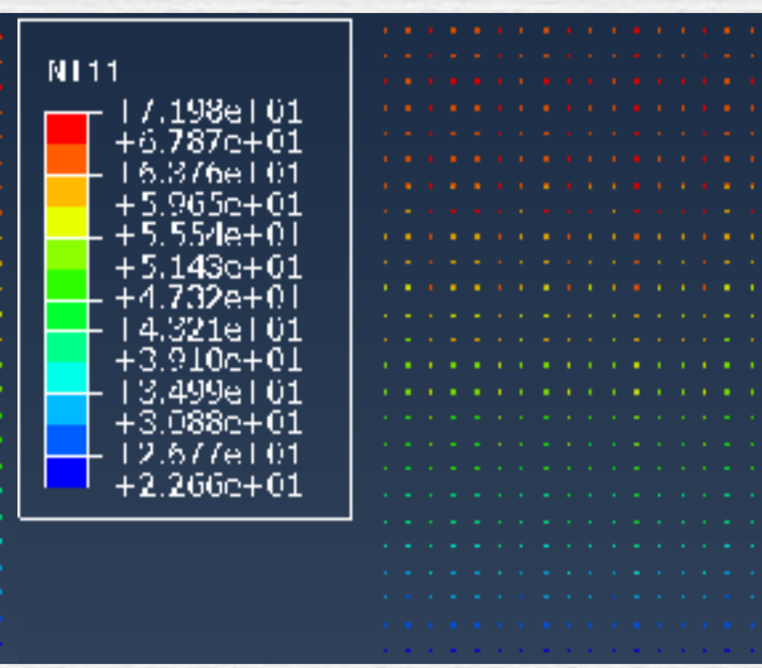
Temperature distribution（2mm）



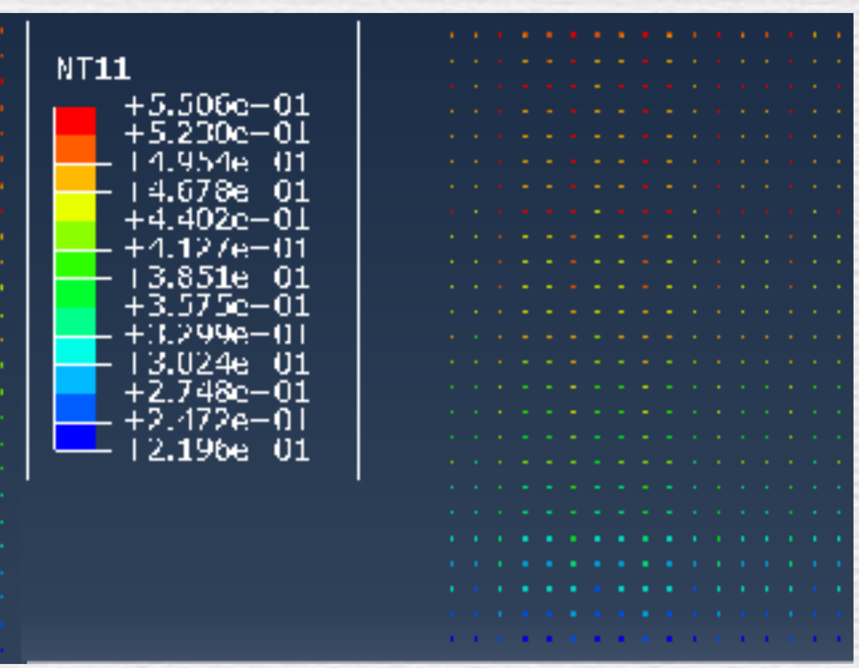
Temperature distribution（3mm）



Temperature distribution（4mm）



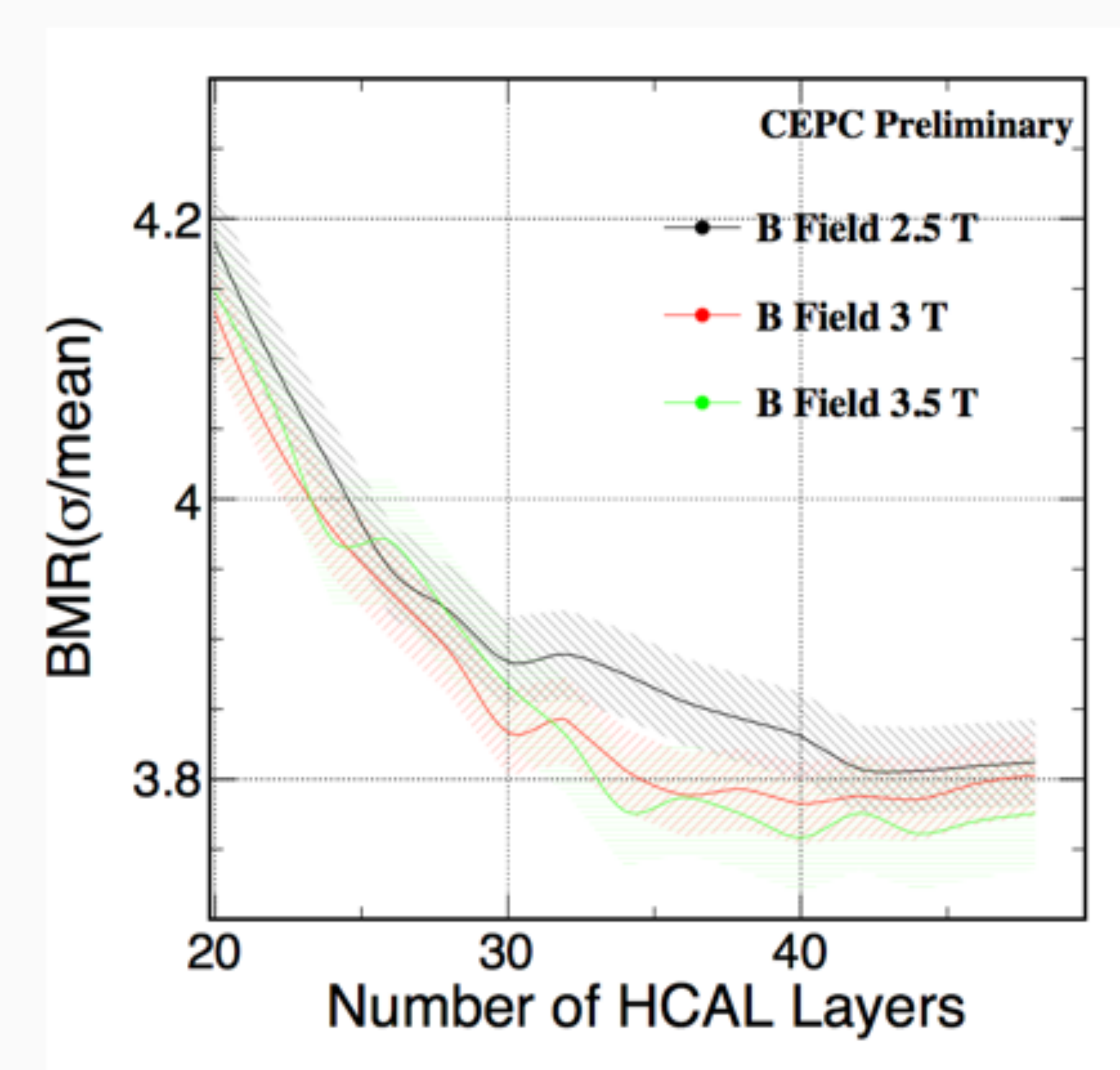
Temperature distribution（5mm）



Temperature distribution（10mm）

HCAL Thickness & B Field

- HCAL: outer layers unused
- Smaller B Field needed

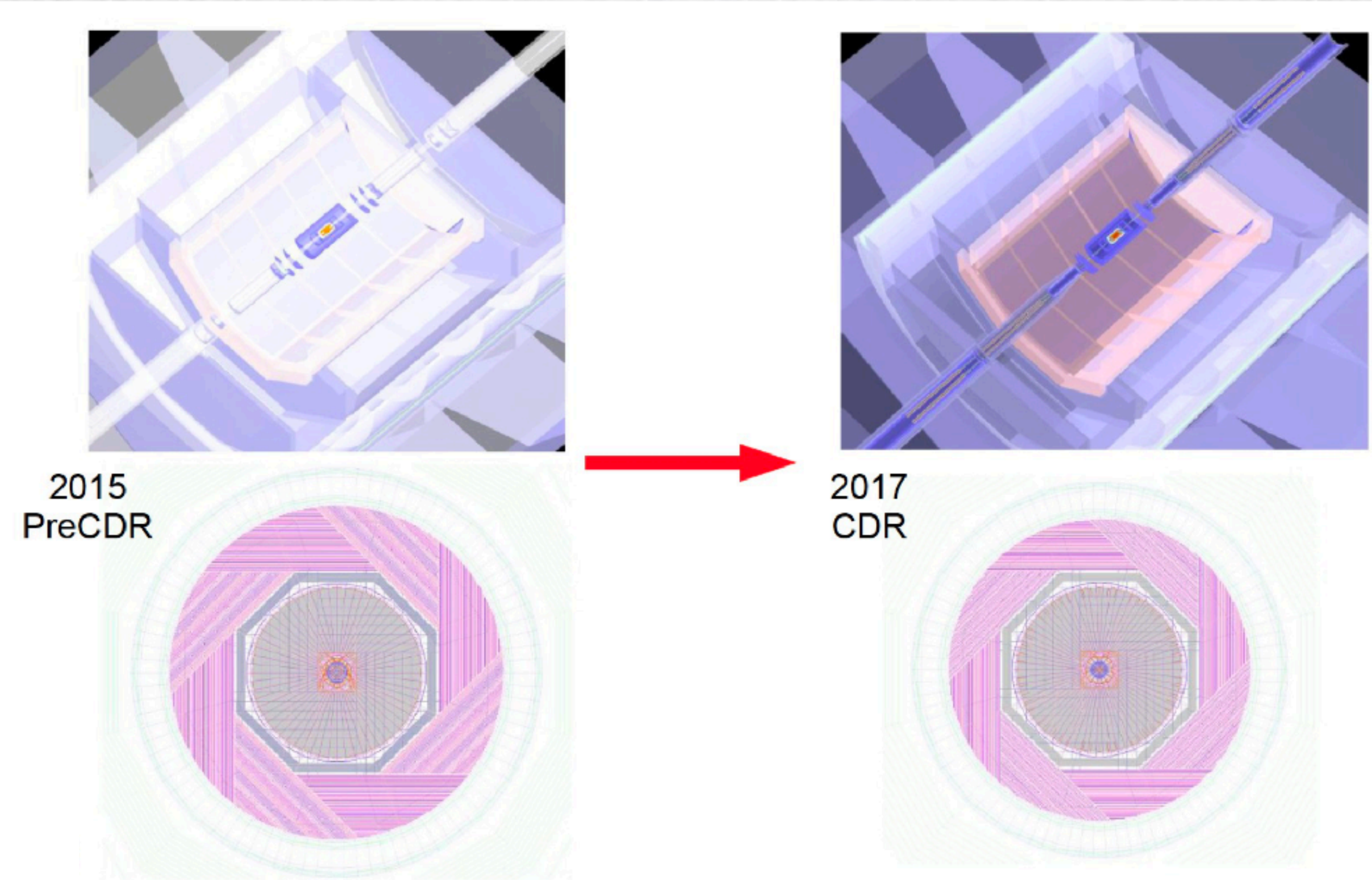


CEPC_V1 vs CEPC_V4

- CEPC_V1: baseline in CEPC preCDR
- CEPC_V4: baseline for CEPC CDR - APODIS

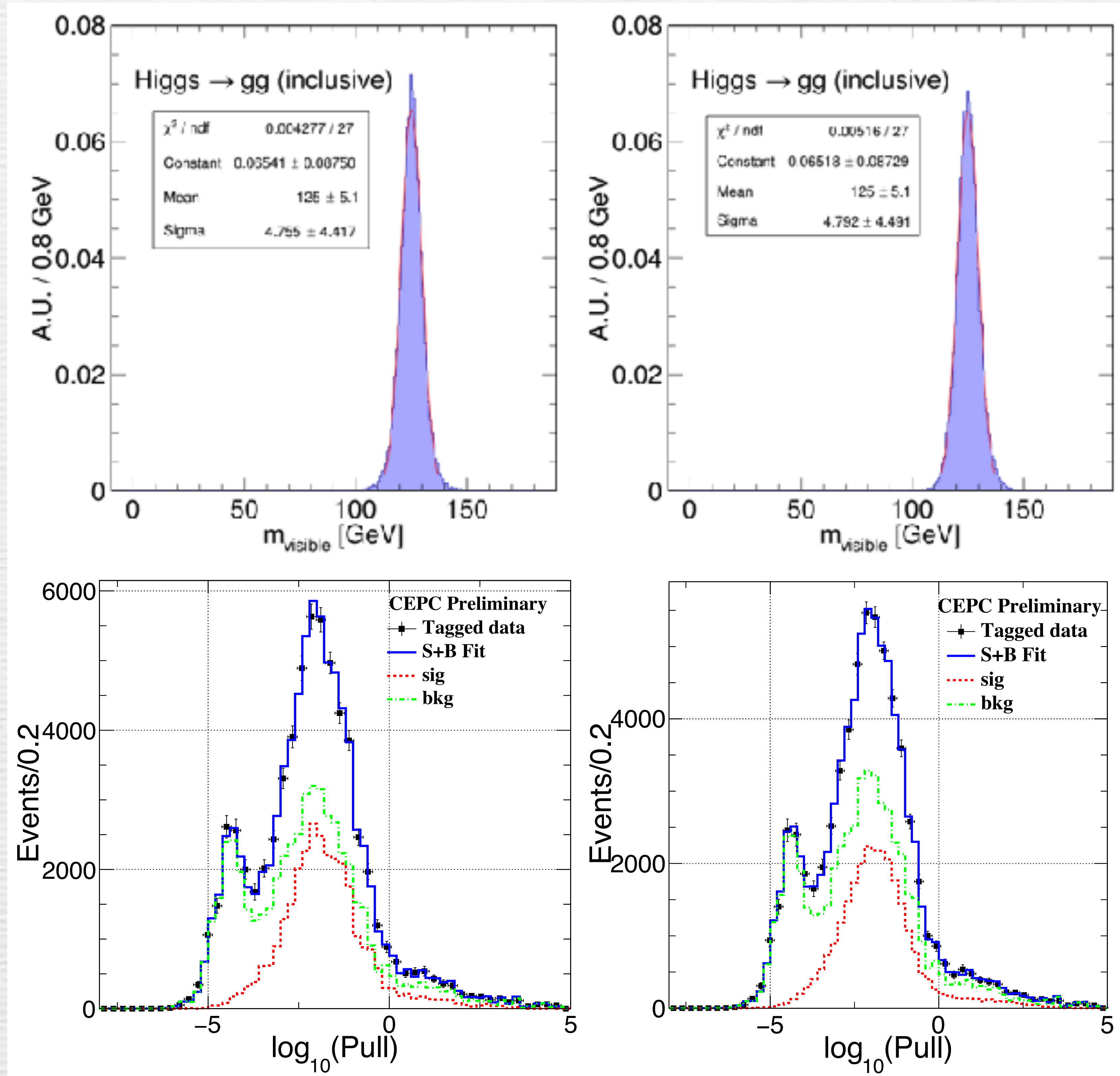
	CEPC_v1 (~ ILD)	APODIS (Optimized)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at 250 GeV; 90mm for bhabha event at 350 GeV
ECAL Cell Size	5 mm	10 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs event at 250 GeV; Margin might be reserved for 350 GeV.

CEPC_V1 vs CEPC_V4



Performances comparison

- BMR:
  - V1(left): 3.80±0.02%
  - V4(right): 3.83±0.02%
- Tau:
  - V1(left): 0.93±0.06%
  - V4(right): 0.97±0.03%



Summary

- Leptonic object reconstruction algorithms developed
  - LICH
  - Tau finding
- APODIS, the baseline detector concept for the CEPC CDR, is established via a series of optimization studies.
  - Reducing B Field by 15%, ECAL readout channel by 75%, HCAL thickness by 20% — the construction cost by ~ 20%.
  - Enhanced the PID performance (by requesting dE/dx & ToF), and maintained the same level of performance on Higgs measurements
- Further collaborations:
  - Beamtest 2018
  - Readout Electronics
  - Thermo-mechanical studies

Publications

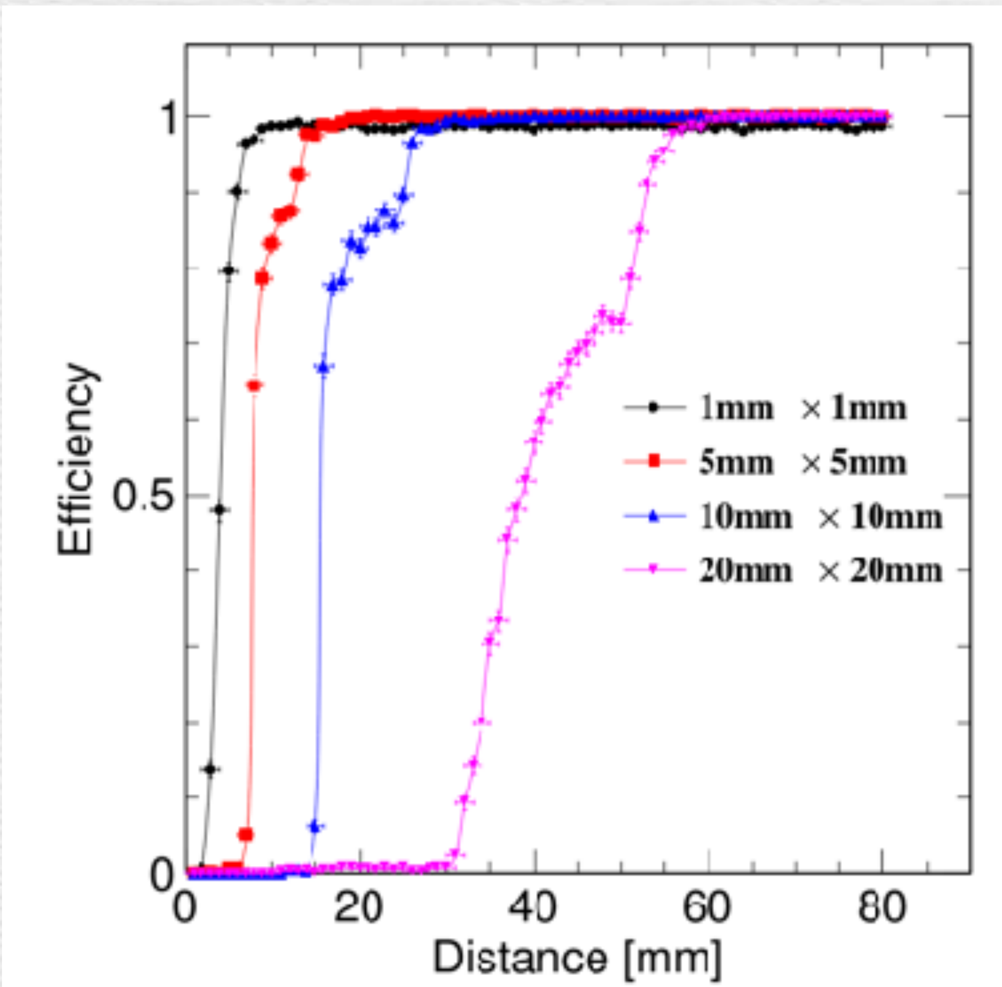
- *Yu, D., Ruan, M., Boudry, V., Videau, H., & Brient J.C. (2017). Lepton identification at particle flow oriented detector for the future e+e- Higgs factories. The European Physical Journal C, 77(9), 591.*
- *Liang, H., & Ruan, M. (2018). Detector Performance and Physics Potential at CEPC. In International Journal of Modern Physics: Conference Series (Vol. 46, p. 1860086). World Scientific Publishing Company.*
- *Zhao, H., Fu, C., Yu, D., Wang, Z., Hu, T., & Ruan, M. (2018). Particle flow oriented electromagnetic calorimeter optimization for the circular electron positron collider. Journal of Instrumentation, 13(03), P03010.*
- *CEPCCEPC-DocDB-id:*
    - *169: Photon reconstruction*
    - *171: Boson separation*
    - *172: Kaon separation, TPC+ToF*
    - *174: Track reconstruction in APODIS*
    - *175: Photon reconstruction in APODIS*
    - *...*

Thank you for your attention!

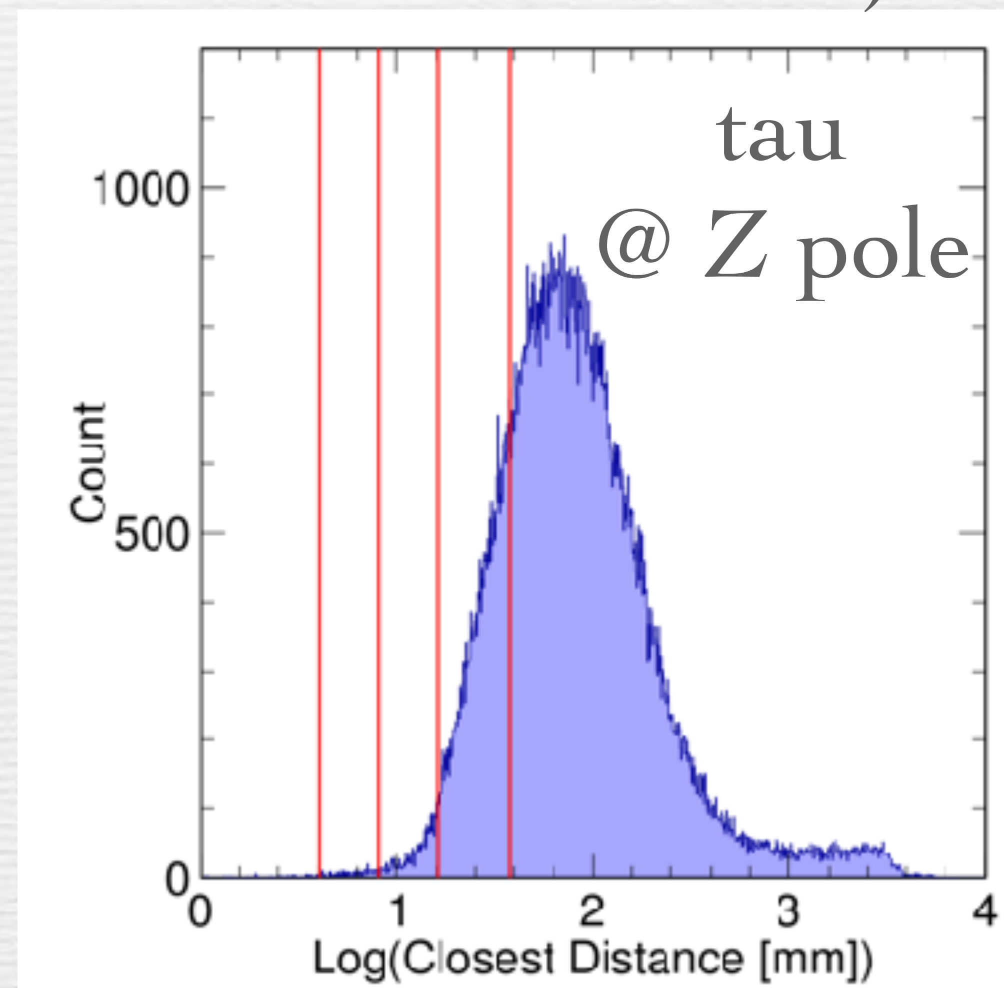
Back up

ECAL Cell Size

The efficiency to separate two photons at different distance for different cell sizes

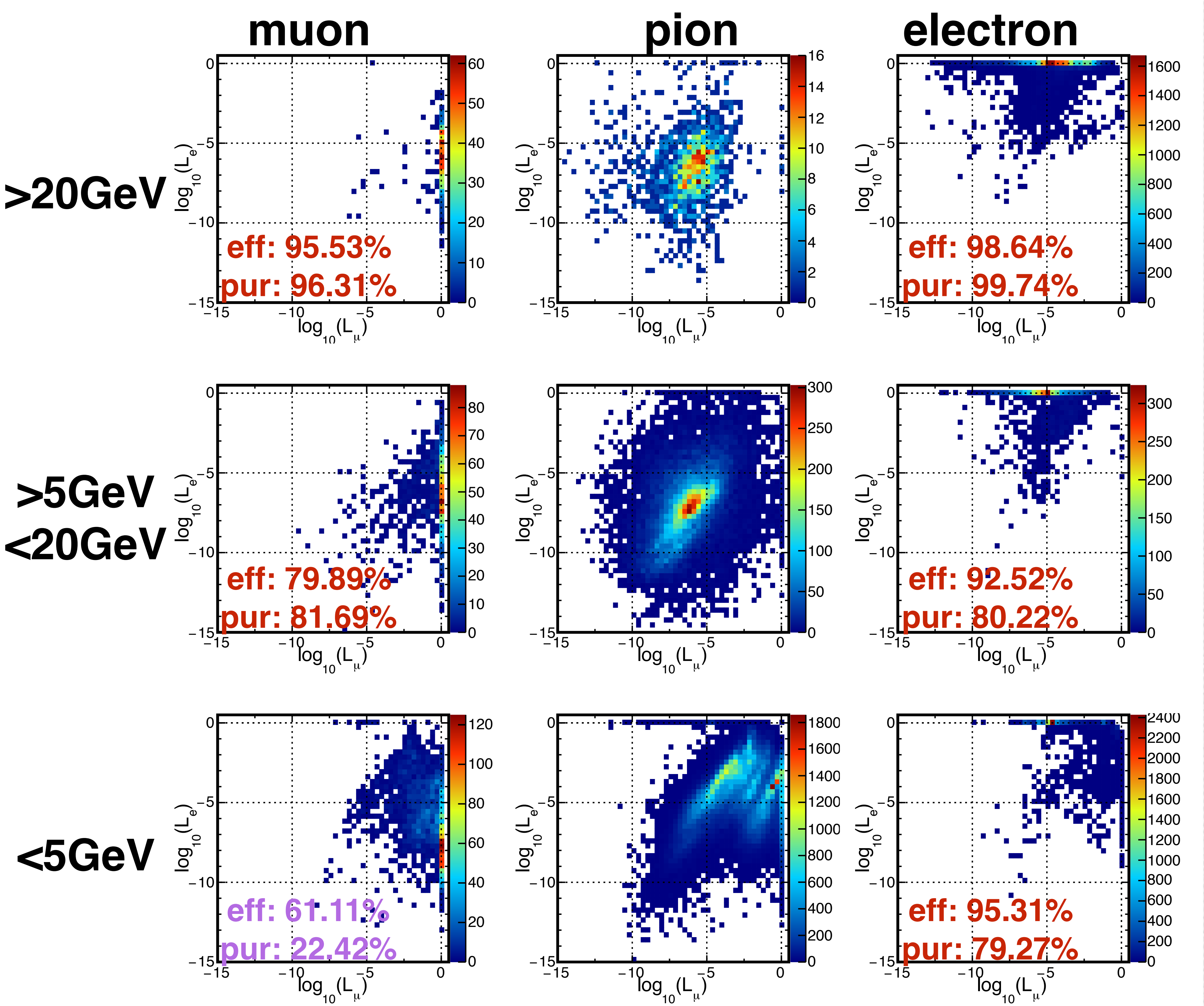


The distance between photon and its closest neighbor in tau events @ Z pole (red lines show the critical separation distance for different cell sizes)



Cell Size (mm^2)	5×5	10×10	20×20
BMR	3.74 ± 0.02 %	3.75 ± 0.02 %	3.93 ± 0.02 %

LICH - Event ID



- eeH/μμH channel
- Different cut for different energy
- Difficult for low energy π/μ
- Event efficiency: 97.06%

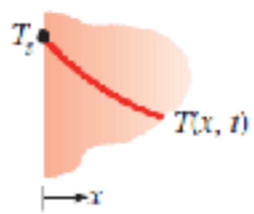
Cooling system optimization

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + q = \rho c_p \frac{\partial T}{\partial t}$$

TABLE 2.2 Boundary conditions for the heat diffusion equation at the surface ($x = 0$)

1. Constant surface temperature

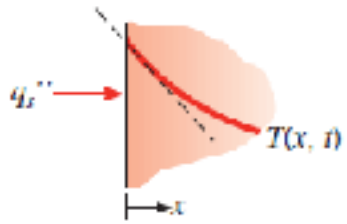
$$T(0, t) = T_s \quad (2.31)$$



2. Constant surface heat flux

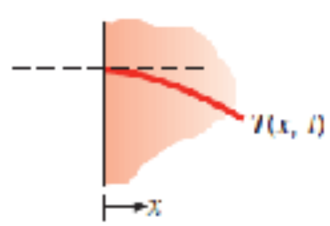
(a) Finite heat flux

$$-k\frac{\partial T}{\partial x}\bigg|_{x=0} = q''_s \quad (2.32)$$



(b) Adiabatic or insulated surface

$$\frac{\partial T}{\partial x}\bigg|_{x=0} = 0 \quad (2.33)$$



3. Convection surface condition

$$k\frac{\partial T}{\partial x}\bigg|_{x=0} = h[T_\infty - T(0, t)] \quad (2.34)$$